PUBERTY IN BEEF BULLS: HORMONE CONCENTRATIONS, GROWTH, TESTICULAR DEVELOPMENT, SPERM PRODUCTION AND SEXUAL AGGRESSIVENESS IN BULLS OF DIFFERENT BREEDS[1]

D. D. Lunstra, J. J. Ford and S. E. Echternkamp

U.S. Department of Agriculture[2,3], *Clay Center, NE 68933*

SUMMARY

Postweaning growth and pubertal traits were studied in Hereford, Angus, Red Poll, Brown Swiss, Hereford-Angus crossbred (H×A) and Angus-Hereford crossbred (A×H) bulls from 7 through 13 months of age. Pubertal factors characterized included body weight, testicular size, hormone concentrations, sexual aggressiveness and sperm production. Puberty was defined as the age at which a bull first produced an ejaculate containing at least 50×10^6 spermatozoa with a minimum of 10% motility. Average pubertal age in days was 264 ± 9 for Brown Swiss, 283 ± 9 for Red Poll, 295 ± 9 for Angus, 296 ± 9 for A×H, 300 ± 8 for H×A and 326 ± 9 for Hereford bulls. Brown Swiss bulls were heaviest (295 kg), while Red Poll and Hereford bulls were lightest (258 and 261 kg) in body weight at puberty.

Concentrations of serum luteinizing hormone (LH) and testosterone (T), averaged across all bulls, increased linearly ($P<.01$) from 7 through 13 months of age. Breed differences in LH concentration were not observed from 7 months of age through puberty. Breed groups with high average T concentrations between 7 and 13 months of age reached puberty earlier than breed groups with low T concentrations. Bulls exhibited first sexual interest approximately 3 weeks before reaching puberty, and attained mating ability approximately 6 weeks after reaching puberty. Brown Swiss bulls were capable of completed matings 83 to 121 days earlier ($P<.01$) than other breed groups.

Although rather large differences in age and body weight at puberty existed among breeds, scrotal circumference at puberty (27.9 ± .2 cm) did not differ ($P>.10$). It is concluded that measurement of scrotal circumference may be a simple method of assessing puberty in beef bulls, regardless of differences in age, weight and breed, and should be a useful tool in the selection of early maturing bulls with minimal effort.

(Key Words: Puberty, Scrotal Circumference, Serum Hormones, Libido, Growth, Breed Differences.)

INTRODUCTION

Description of pubertal development in bulls has been limited primarily to the dairy breeds, and few characterizations have been published for beef bulls (Barber and Almquist, 1975; Swanson *et al.*, 1971; Wolf *et al.*, 1965). Selection and management of young beef bulls is hampered by the lack of information on puberty, and breed comparisons and delineation of breed differences at puberty have yet to be defined. An understanding of the sexual maturation processes in bulls is necessary before attempts can be made to alter or exploit rates of maturation to the advantage of the beef industry.

The primary objectives of this study were to characterize the changes associated with onset of puberty in beef bulls and to define breed differences at puberty, including the relationships between endocrine, anatomical, spermatogenic and behavioral factors.

MATERIALS AND METHODS

Thirty-one straightbred and crossbred bulls, born in May 1974, were evaluated from 7 through 13 months of age. Breed groups and

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number of bulls per group were: five Hereford (H), five Angus (A), six H×A crossbreds (H×A), five A×H crossbreds (A×H), five Red Poll (RP) and five Brown Swiss (BS). Bulls with adjusted weaning weights approximating the average of large peer groups and with dams of similar age were selected to represent each breed. All bulls had been subjected to the same managerial and environmental influences from birth. Bulls were weaned at 131 ± .2 days of age and were penned together through 13 months of age. Evaluation of sexual aggressiveness, testicular size, body weight, blood hormones and sperm production was performed every 2 weeks from December to June. Bulls were fed the same ration from weaning to completion of the study. The ration consisted of corn silage (60%, Ref. No. 3-08-153), alfalfa haylage (20%, Ref. No. 3-03-150), corn (18%, Ref. No. 4-02-931) and 2% supplement fed *ad libitum*. On a dry matter basis, the ration contained 2.44 Mcal NE/kg and 12% crude protein, and daily dry matter consumption averaged 7.9 kg/head/day during the 7-month evaluation period.

Blood was collected by jugular puncture within 1 min after restraint of bulls in a squeeze chute. One 15 ml blood sample was collected from each bull biweekly and individuals were sampled in random order. Blood was allowed to coagulate under refrigeration and serum stored at −20 C until assayed. Immediately following blood collection, scrotal circumference was measured as described by Hahn *et al.* (1969) and semen was collected by electroejaculation. Detachment of the sheath (prepuce) was evaluated by observation of the erect, extended penis during electroejaculation. Complete detachment of the sheath was recorded when the penis could be fully-extended with no vestiges of preputial attachment along the body of the penis. The following day, sexual aggressiveness (libido) was evaluated. Libido tests were conducted in a semicircular pen, 8 m in radius, visually separated from untested bulls by solid plywood panels. Each bull was exposed to three ovariectomized, estrus-induced heifers during a 5-min test period, and the test period began when the bull entered the pen. Recorded behavior included first sexual interest (first oriented mount), abortive mounts and completed matings. Any mount that did not culminate in ejaculation was classified as abortive.

Testosterone (T) was quantified by radioimmunoassay utilizing antibody S-741-#2 purchased from Dr. G. Abraham, UCLA School of Medicine, Harbor General Hospital, Torrance, CA. Antibody specificity has been published previously (Abraham *et al.*, 1972). One-hundred microliters of serum, .4 ml of saline and one drop of NH_4OH (30%, w/w) were placed in a vial and extracted twice with 2 ml of diethyl ether. Ether extracts were transferred to 12 × 75 mm tubes, evaporated under nitrogen gas flow and assayed directly without further purification. Minimum sensitivity of the assay was 25 pg of testosterone. The intraassay coefficient of variation for duplicate determinations was less than 10%. The interassay coefficient of variation for a pool of bull serum containing 3.5 ng/ml was 9%. Correlation between T added to serum and the amount determined in excess of initial concentration was .993 for duplicate determinations of four levels of T ranging from .25 to 2.0 nanograms.

Serum luteinizing hormones (LH) concentrations were determined by use of a double antibody radioimmunoassay similar to that reported by Niswender *et al.* (1969). Purified ovine LH[4] was labelled with ^{125}I by the method of Greenwood *et al.* (1963) and separated on a 1 × 30 cm Sephadex G-100 column. The descending portion of the radiolabeled LH peak was diluted with .1 gelatin-PBS to 50,000 cpm/milliliter. The LH antibody[5] bound more than 90% of the LH-^{125}I at a dilution of 1:300 and 45 to 50% at a working dilution of 1:40,000. Crossreactivity of the antibody was parallel and equal to the concentration of bioassayable LH in National Institute of Health preparations of prolactin, follicle stimulating hormone, growth hormone and thyroid stimulating hormone. The sheep anti-rabbit γ-globulin[5] was used at a dilution of 1:80. Each assay was composed of 16 different concentrations of purified bovine LH standard[6] ranging from 25 pg to 50 ng/tube, 75 unknown serum samples and aliquots of two plasma pools. Aliquots of .1 and .2 ml were assayed for each unknown sample and the intraassay coefficient

[4] Purified ovine LH (LER-1056-C2) was obtained from Dr. L. E. Reichert, Emory University, Atlanta, GA.

[5] Antiserum to bovine LH (DJB 3-12/11) and sheep anti-rabbit γ-globulin (DJB 5×3) were obtained from Dr. D. J. Bolt, USDA-ARS, Beltsville, MD.

[6] Purified bovine LH (NIH-LH-B8), used as a standard, was a gift from the Endocrine Study Section, NIH, Bethesda, MD.

of variation was less than 10%. The two bovine plasma pools had LH concentrations of .7 and 8.1 ng/ml and the interassay coefficients of variation were 9.3 and 5.3%, respectively. Recovery of added amounts of LH standard from .2 ml of serum ranged from 97 to 100%.

Least squares means were obtained and analyzed by split-plot analysis of variance for data with unequal subclass numbers using the methods of Harvey (1975). Mean differences were tested using Duncan's multiple range test.

RESULTS

Hormone Concentrations. Serum LH concentrations increased linearly ($P<.01$) between 7 and 13 months of age (table 1) for all bulls combined ($y = .14 + .25x$, $r = .39$). Breed differences in LH concentrations were not observed between 7 and 11 months of age (i.e., through puberty). Mean LH concentration averaged over the entire evaluation period was higher for RP than for H bulls ($P<.05$).

Serum T concentrations (table 2) averaged for all bulls also increased linearly ($P<.01$) between 7 and 13 months of age ($y = .93 + .46x$, $r = .37$). Hereford, H×A and A×H bulls exhibited linear increases ($P<.01$) between 7 and 13 months, while more complex patterns and greater fluctuations from month to month were observed for A, RP and BS bulls (table 3). When averaged over the entire evaluation period, BS and RP bulls possessed higher T concentrations ($P<.05$) than H and H×A bulls. Correlations between T and LH concentrations are given in table 3.

Growth. Growth patterns for the six breed groups are shown in figure 1. Body weight increased linearly with age ($P<.01$) within each breed group and when averaged across all bulls. Hereford bulls weighed less and BS bulls were heavier than other breed groups throughout the study ($P<.05$). Average daily gains were .59 ± .04, .69 ± .05, .72 ± .04, .74 ± .06, .76 ± .03 and .87 ± .03 kg/day for H, A, H×A, A×H, RP and BS bulls, respectively, between 7 and 13 months of age. Daily gains for H and BS bulls were different ($P<.01$), while intermediate breed groups did not differ from each other ($P>.10$). Correlations between body weight and other characteristics are given in table 3.

Testicular Development. Scrotal circumference increased linearly with age ($P<.01$) within each breed group (figure 2) and when averaged across all bulls ($y = 12.63 + 1.52x$ $r = .88$).

TABLE 1. SYSTEMIC LH CONCENTRATION IN BEEF BULLS BETWEEN 7 AND 13 MONTHS OF AGE[a]

Breed group[b]	Months of age							
	7	8	9	10	11	12	13	Average
H	1.3^{c}	1.7^{c}	2.5^{c}	3.6^{c}	2.4^{c}	2.3^{c}	2.0^{c}	$2.3 \pm .2^{c}$
H × A	1.8^{c}	1.8^{c}	1.7^{c}	3.5^{c}	2.3^{c}	3.3^{c}	3.5^{cd}	$2.5 \pm .2^{cd}$
A × H	1.6^{c}	1.7^{c}	2.8^{c}	2.7^{c}	2.8^{c}	2.9^{c}	2.7^{cd}	$2.4 \pm .2^{cd}$
A	3.1^{c}	2.0^{c}	2.2^{c}	4.1^{c}	3.1^{c}	2.5^{c}	2.1^{c}	$2.7 \pm .2^{cd}$
RP	1.8^{c}	3.3^{c}	2.5^{c}	3.4^{c}	2.1^{c}	6.1^{d}	5.7^{e}	$3.2 \pm .2^{d}$
BS	1.8^{c}	2.2^{c}	2.1^{c}	2.8^{c}	3.1^{c}	2.9^{c}	4.8^{de}	$2.8 \pm .2^{cd}$
All bulls	1.9 ± .3	2.1 ± .3	2.3 ± .3	3.3 ± .3	2.6 ± .3	3.3 ± .3	3.5 ± .3	2.7 ± .1

[a]Least squares means expressed in ng/ml. Each monthly value represents the average of two biweekly samples collected per bull. Mean values with different superscripts within a column are different ($P<.05$).

[b]Breed abbreviations are Hereford (H), Angus (A), H × A crossbreds (H × A), A × H crossbreds (A × H), Red Poll (RP) and Brown Swiss (BS).

TABLE 2. SYSTEMIC TESTOSTERONE CONCENTRATION IN BEEF BULLS BETWEEN 7 AND 13 MONTHS OF AGE[a]

Breed group[b]	Months of age 7	8	9	10	11	12	13	Average
H	.7^{c}	1.1^{c}	4.4^{c}	5.8^{cd}	4.5^{c}	5.1^{cd}	4.9^{c}	4.0 ± .5^{c}
H × A	4.4^{d}	3.1^{cd}	3.2^{c}	4.2^{c}	4.4^{c}	6.4^{cd}	6.2^{cd}	4.7 ± .4^{c}
A × H	3.1^{cd}	4.1^{cd}	3.3^{c}	5.1^{cd}	6.3^{c}	4.8^{cd}	8.0^{cd}	5.1 ± .4^{cd}
A	6.2^{d}	3.5^{cd}	5.4^{cd}	2.9^{c}	5.6^{c}	7.7^{c}	7.8^{cd}	5.7 ± .4^{cd}
RP	6.2^{d}	6.2^{d}	7.9^{d}	8.9^{e}	7.4^{c}	6.5^{cd}	8.4^{d}	7.5 ± .4^{d}
BS	5.4^{d}	6.4^{d}	7.5^{d}	7.7^{de}	4.3^{c}	4.3^{d}	8.7^{d}	6.4 ± .4^{d}
All bulls	4.3 ± .6	4.1 ± .6	5.2 ± .6	5.7 ± .6	5.5 ± .6	5.8 ± .6	7.3 ± .6	5.6 ± .2

[a]Least squares means expressed in ng/ml. Each monthly value represents the average of two biweekly samples collected per bull. Mean values with different superscripts within a column are different ($P<.05$).

[b]Breed abbreviations are Hereford (H), Angus (A), H × A crossbreds (H × A), A × H crossbreds (A × H), Red Poll (RP) and Brown Swiss (BS).

TABLE 3. CORRELATIONS BETWEEN AGE, BODY WEIGHT, SCROTAL CIRCUMFERENCE, LUTEINIZING HORMONE AND TESTOSTERONE FOR BEEF BULLS BETWEEN 7 AND 13 MONTHS OF AGE

Breed group[b]	Age *vs* LH	Age *vs* T	Age *vs* SC	Age *vs* WT	WT *vs* LH	WT *vs* T	WT *vs* SC	SC *vs* LH	SC *vs* T	LH *vs* T
H	.27*	.36**	.84**	.92**	.30**	.48**	.95**	.36**	.51**	.55**
H × A	.32**	.26**	.92**	.93**	.46**	.31**	.91**	.30**	.26**	.47**
A × H	.26*	.35**	.89**	.93**	.18	.28*	.87**	.33**	.29*	.46**
A	.00	.22	.80**	.90**	-.02	.18	.88**	.02	.11	.09
RP	.33**	.09	.82**	.88**	.21	.22	.88**	.33**	.40**	.37**
BS	.42**	.04	.78**	.95**	.40**	.08	.70**	.38**	.14	.31**
All bulls	.39**	.37**	.88**	.85**	.37**	.26**	.80**	.44**	.51**	.38**

[a]Abbreviations for correlated characteristics are WT (body weight), LH (luteinizing hormone), T (testosterone) and SC (scrotal circumference).

[b]Breed abbreviations are Hereford (H), Angus (A), H × A crossbreds (H × A), A × H crossbreds (A × H), Red Poll (RP) and Brown Swiss (BS).

**($P<.01$), *($P<.05$).

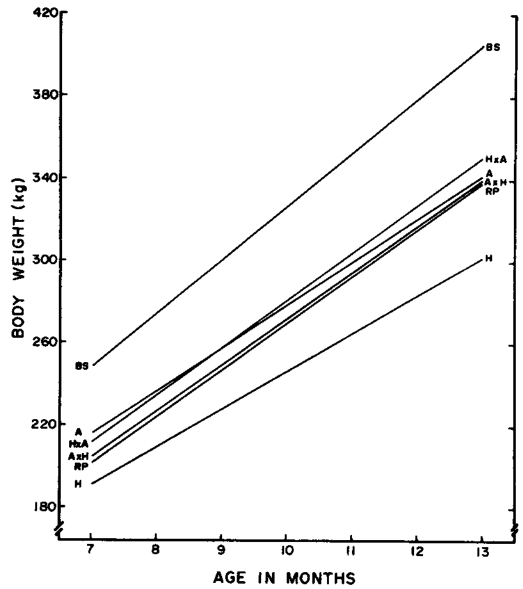

Figure 1. Relationship between body weight and age in breeds of beef bulls between 7 and 13 months of age. Hereford (H, y = 61.50 + 18.53X, r = .92), Angus (A, y = 68.81 + 20.97X, r = .90), HXA crossbred (HXA, y = 48.87 + 23.21X, r = .93), AXH crossbred (AXH, y = 46.69 + 22.49X, r = .93), Red Poll (RP, y = 41.55 + 22.84X, r = .88) and Brown Swiss (BS, y = 66.45 + 26.04X, r = .95).

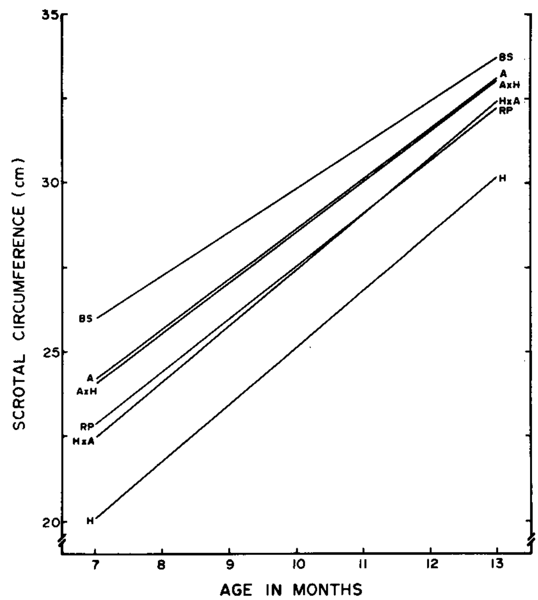

Figure 2. Relationship between scrotal circumference and age in breeds of beef bulls between 7 and 13 months of age. Hereford (H, y = 8.35 + 1.68X, r = .84), Angus (A, y = 13.82 + 1.48X, r = .80), HXA crossbred (HXA, y = 10.82 + 1.66X, r = .92), AXH crossbred (AXH, y = 13.53 + 1.50X, r = .89) Red Poll (RP, y = 11.96 + 1.56X, r = .82) and Brown Swiss (BS, y = 17.02 + 1.28X, r = .78).

Testis size, as indicated by scrotal circumference (Hahn *et al.*, 1969), was smaller (P<.01) for H bulls and larger (P<.01) for BS bulls than for other breed groups throughout the study. Correlations of scrotal circumference to age, weight and hormone concentrations are given in table 3.

Sperm Production. Spermatozoa appeared in ejaculates from BS bulls at a much younger age (P<.01) than in other bull groups (table 4), with one BS bull having immotile sperm present in the first electroejaculated sample at 210 days of age. Brown Swiss bulls were also heavier than other breed groups at first sperm production, weighing 25 kg more than A (P<.05) and 29, 29, 39 and 49 kg more than H x A, AxH, RP and H bulls (P<.01). Breed differences in scrotal circumference at first sperm production were not as marked as were differences in age and weight at first sperm (table 4). Scrotal circumference in crossbred groups did not differ (P>.10) at first sperm production but tended to be more similar to straightbred bulls of the sire breed than to those of the dam breed (i.e., HxA were similar to H, and AxH were similar to A).

At first production of motile sperm, BS bulls were 26 to 47 days younger and 21 to 39 kg heavier than other breed groups (P<.05). The time lag between appearance of first sperm and production of first motile sperm was very short for A, AxH and BS bulls (8, 5 and 11 days) and much longer (P<.05) for H, HxA and RP bulls (28, 24 and 31 days). There were no breed differences in scrotal circumference at production of first motile sperm (P>.10), and average circumference for all bulls was 27.0 ± .3 cm (table 4).

At first production of 50 x 10^6 sperm possessing a minimum of 10% progressive motility, BS bulls were 19 to 62 days younger and 16 to 37 kg heavier than other bull groups (table 4). Hereford bulls reached this criterion of puberty later (P<.05) than all other breed groups. There were no breed differences (P>.10) in scrotal circumference at production of 50 x 10^6 sperm with 10% motility (table 4). The range in scrotal circumference at puberty (i.e., 50 x 10^6 sperm) was 25.9 to 30.1 cm, and 32% of the bulls reached puberty at ⩽27 cm,

TABLE 4. RELATIONSHIPS BETWEEN PUBERTAL CHARACTERISTICS OF VARIOUS BREEDS OF BEEF BULLS[a]

Pubertal characteristic	Breed means[b]						All bulls
	H	H X A	A X H	A	RP	BS	
Age in days at:							
First sperm	266^{de}	258^{de}	268^{d}	265^{de}	252^{e}	236^{f}	258 ± 2
First motile sperm	294^{d}	282^{d}	273^{d}	273^{d}	283^{d}	247^{e}	275 ± 3
50 X 10^6 sperm (10% motile)[c]	326^{d}	300^{e}	296^{e}	295^{e}	283^{ef}	264^{f}	294 ± 4
First sexual interest	298^{d}	300^{d}	276^{de}	259^{de}	269^{de}	236^{e}	273 ± 8
First completed mating	371^{d}	366^{de}	341^{de}	354^{de}	333^{e}	250^{f}	336 ± 5
Sheat-penis detachment	329^{d}	317^{d}	313^{de}	321^{d}	294^{e}	244^{f}	303 ± 3
Weight in kilograms at:							
First sperm	223^{d}	243^{de}	243^{de}	247^{e}	233^{de}	272^{f}	243 ± 4
First motile sperm	242^{d}	260^{de}	246^{d}	254^{d}	258^{de}	281^{f}	257 ± 3
50 X 10^6 sperm (10% motile)[c]	261^{d}	279^{de}	264^{d}	273^{de}	258^{d}	295^{e}	273 ± 4
First sexual interest	240^{d}	274^{d}	252^{d}	241^{d}	244^{d}	267^{d}	254 ± 6
First completed mating	284^{d}	332^{e}	304^{de}	322^{e}	293^{de}	283^{d}	305 ± 6
Sheat-penis detachment	270^{d}	296^{e}	280^{d}	295^{e}	265^{d}	279^{d}	281 ± 4
Scrotal circumference (cm) at:							
First sperm	23.9^{d}	24.8^{de}	26.6^{de}	27.4^{e}	25.6^{de}	26.1^{de}	25.9 ± .4
First motile sperm	25.9^{d}	26.4^{d}	27.0^{d}	28.3^{d}	27.5^{d}	26.5^{d}	27.0 ± .3
50 X 10^6 sperm (10% motile)[c]	27.9^{d}	27.8^{d}	28.4^{d}	28.6^{d}	27.5^{d}	27.2^{d}	27.9 ± .2
First sexual interest	24.6^{d}	27.6^{d}	27.7^{d}	26.3^{d}	26.3^{d}	26.6^{d}	26.6 ± .5
First completed mating	29.1^{de}	30.5^{e}	30.5^{e}	31.1^{e}	29.5^{de}	27.6^{d}	29.8 ± .4
Sheath-penis detachment	27.4^{d}	28.8^{d}	29.6^{d}	29.8^{d}	28.4^{d}	27.5^{d}	28.6 ± .3

[a]Least squares means. Breed means with different superscripts within each row are different ($P<.05$).

[b]Breed abbreviations are Hereford (H), Angus (A), H X A crossbreds (H X A), A X H crossbreds (A X H), Red Poll (RP) and Brown Swiss (BS).

[c]Based on the first production of an ejaculate containing at least 50 X 10^6 spermatozoa with a minimum of 10% motility.

52% at ≤28 cm, 74% at ≤29 cm and 97% at ≤30 circumference.

Sexual Aggressiveness. Brown Swiss bulls exhibited first sexual interest at a younger (P<.05) age than did bulls of H and H×A breeds and were capable of completed matings 83 to 121 days earlier (P<.01) than other breed groups (table 4). Hereford and H×A bulls were the latest to exhibit sexual interest and acquire mating ability. Mean age at first completed mating tended to be earlier in crossbreds combined (H×A and A×H) than in H and A straightbreds combined (354 *vs* 363 days of age). No difference (P>.10) existed between breed groups for weight at first sexual interest, but BS and H×A tended to be the heaviest (table 4). Comparing body weight at first completed mating, BS and H bulls weighed the least and A and H×A were the heaviest (P<.05) breed groups.

Sheath-Penis Detachment. Average age at complete sheath-penis detachment was intermediate between age at first attempted mating and age at first completed mating in all bull groups (table 4). Complete detachment occurred 50 to 85 days earlier (P<.01) in BS bulls than in other breed groups. Three bulls (one each in A, H×A and A×H groups) were able to complete their first mating before separation of the penis and sheath was complete. The time lag between first sexual interest and complete sheath-penis detachment was 62 days for A bulls, a longer (P<.01) time period than the 8 to 37 days required for other breed groups.

Discussion

In its fullest sense, puberty occurs when bulls attain the ability to produce viable spermatozoa, exhibit sexual aggressiveness and penile development permits intromission and ejaculation (Foote, 1969). However, since these three events do not occur simultaneously, a variety of definitions of puberty have been proposed. The most widely accepted is to define puberty as the age at which the first ejaculate containing a minimum of 50×10^6 total spermatozoa with at least 10% progressive motility is collected (Barber and Almquist, 1975; Killian and Amann, 1972; Wolf *et al.*, 1965). The discussion of pubertal characteristics below will refer to this definition of puberty. Other criteria of puberty, such as first sperm, first motile sperm, first sexual interest, and first completed mating, have been included in the results section to facilitate comparison to other publications.

Averaged across all bulls in this study, serum concentrations of LH increased (P<.01) linearly with advancing age around the time of puberty. This pattern is in agreement with the general increases reported for young Hereford (Swanson *et al.*, 1971) and Holstein bulls (MacMillan and Hafs, 1968). Increases in LH concentrations preceding puberty also have been reported in rats (Davidson, 1974) and rams (Lee *et al.*, 1976). Concentrations of serum T also increased (P<.01) linearly with advancing age when averaged across all bulls between 7 and 13 months of age. The increase in T concentration through puberty agrees with published data for Holstein (Rawlings *et al.*, 1972) and Friesian bulls (Secchiari *et al.*, 1976) and is supported by reports of similar neopubertal increases in systemic T levels for rams (Lee *et al.*, 1976) and rats (Resko *et al.*, 1968).

Our observation that LH and T increased gradually as bulls approached puberty supports the hypothalamic desensitization theory of sexual maturation (Odell and Swerdloff, 1974). However, it has been reported that induced LH surges do not stimulate increased T secretion until bulls are 6 months of age or older (Mongkonpunya *et al.*, 1975), indicating that the testes of prepubertal bulls become more responsive to LH stimulation as puberty approaches. Thus, our data also supports the theory of increasing Leydig cell responsiveness.

In general, breed groups with high average T tended to reach puberty earlier than breed groups with low average T concentrations (table 2). The correlation between average T and age at puberty was −.51 (P<.01). Average T concentration was not related (P>.10) to body weight (r = .07), scrotal circumference (r = .22) or LH concentration at puberty (r = .26), nor was it related to age at first sexual interest (r = −.26). However, stronger (P<.01) relationships existed between average T concentrations and age at complete sheath-penis detachment (r = −.48) and age at first completed mating (r = −.46), supporting the androgen-dependency of preputial separation (Korenbrot *et al.*, 1977) and indicating that attainment of mating ability is related to circulating T concentrations (Blockey, 1975).

Scrotal circumference at puberty (27.9 ± .2 cm) was relatively constant among breeds and across bulls differing widely in age and weight at puberty (table 4). The correlation between scrotal circumference averaged across the entire evaluation period and age at puberty was −.65 (P<.01), indicating that scrotal circumference may be more useful than other characteristics for the prediction of age at puberty. The average of two measurements of scrotal circumference, one taken at 7 months and one at 10 months of age, served to predict age at puberty even more accurately (figure 3). The predictive value of the 7 and 10 month average did not appear to be affected by breed, and measurement of scrotal circumference may be a reliable means of identifying pubertal age in bulls, regardless of differences in body weight, calendar age or breed.

Scrotal circumference is more easily obtained than sperm production or behavioral measurements and should be useful in the selection of beef bulls for early sexual maturity. The potential of selection programs based on scrotal circumference is reinforced by the rather high heritability reported for this characteristic in bulls (h = .67, Coulter *et al.*, 1976). In addition, the selection of young male sheep and mice for rate of testicular growth has been shown to be related to earlier puberty and improved reproductive capacity in genetically-related females (Land and Carr, 1975; Islam *et al.*, 1976). However, it is known that nutrition and environment can affect pubertal age in bulls (VanDemark, 1956), and the effect of

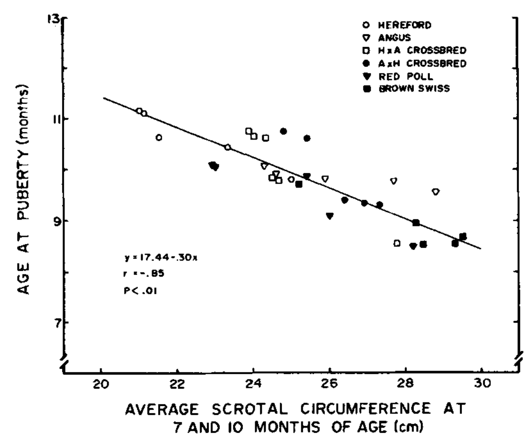

Figure 3. Relationship between average scrotal circumference and pubertal age. Average scrotal circumference is the mean of two measurements, one taken at 7 months and one taken at 10 months of age. Symbols represent individual bulls of the breed groups indicated. No point deviates more than ±.9 months from the regression line.

these factors on testis growth requires further investigation.

LITERATURE CITED

Abraham, G. E., J. E. Buster, L. A. Lucas, P. C. Corrales and R. C. Teller. 1972. Chromatographic separation of steroid hormones for use in radioimmunoassay. Analyt. Letters 5:509.

Barber, K. A. and J. O. Almquist. 1975. Growth and feed efficiency and their relationship to puberal traits of Charolais bulls. J. Anim. Sci. 40:288.

Blockey, M. A. deB. 1975. Studies on the social and sexual behaviour of bulls. Ph.D. Thesis, University of Melbourne, School of Veterinary Science, Melbourne, Australia.

Coulter, G. H., T. R. Rounsaville and R. H. Foote. 1976. Heritability of testicular size and consistency in Holstein bulls. J. Anim. Sci. 43:9.

Davidson, J. M. 1974. Hypothalamic-pituitary regulation of puberty: evidence from animal experimentation. *In* M. M. Grumbach, G. D. Grave and F. E. Mayer (Ed.) The Control of the Onset of Puberty, p. 79-103. John Wiley and Sons, New York.

Foote, R. H. 1969. Physiological aspects of artificial insemination. *In* H. H. Cole and P. T. Cupps (Ed.) Reproduction in Domestic Animals, Second Ed., p. 313-353. Academic Press, New York.

Greenwood, F. D., W. M. Hunter and J. S. Glover. 1963. The preparation of ^{131}I-labelled human growth hormone of high specific radioactivity. Biochem. J. 90:114.

Hahn, J., R. H. Foote and G. E. Seidel, Jr. 1969. Testicular growth and related sperm output in dairy bulls. J. Anim. Sci. 29:41.

Harvey, W. R. 1975. Least squares analysis of data with unequal sub-class numbers. USDA, ARS H-4.

Islam, A. B. M. M., W. G. Hill and R. B. Land. 1976. Ovulation rate of lines of mice selected for testis weight. Genet. Res. (Cambridge) 27:23.

Killian, G. J. and R. P. Amann. 1972. Reproductive capacity of dairy bulls. IX. Changes in reproductive organ weights and semen characteristics of Holstein bulls during the first thirty weeks after puberty. J. Dairy Sci. 55:1631.

Korenbrot, C. C., I. T. Huhtaniemi and R. I. Weiner. 1977. Preputial separation as an external sign of pubertal development in the male rat. Biol. Reprod. 17:298.

Land, R. B. and W. R. Carr. 1975. Testis growth and plasma LH concentration following hemicastration and its relation with female prolificacy in sheep. J. Reprod. Fertil. 45:495.

Lee, V. W. K., I. A. Cumming, D. M. de Kretser, J. K. Findlay, B. Hudson and E. J. Keogh. 1976. Regulation of gonadotropin secretion in rams from birth to sexual maturity. I. Plasma LH, FSH and testosterone levels. J. Reprod. Fertil. 46:1.

MacMillan, K. L. and H. D. Hafs. 1968. Pituitary and hypothalamic endocrine changes associated with reproductive development of Holstein bulls. J. Anim. Sci. 27:1614.

Mongkonpunya, K., H. D. Hafs, E. M. Convey, H. A. Tucker and W. D. Oxender. 1975. Serum luteinizing hormone, testosterone and androstenedione in pubertal and prepubertal bulls after gonadotropin releasing hormone. J. Anim. Sci. 40:682.

Niswender, G. D., L. E. Reichert, Jr., A. R. Midgley, Jr. and A. V. Nalbandov. 1969. Radioimmunoassay for bovine and ovine luteinizing hormone. Endocrinology 84:1166.

Odell, W. D. and R. S. Swerdloff. 1974. The role of the gonads in sexual maturation. *In* M. M. Grumbach, G. D. Grave and F. E. Mayer (Ed.) The Control of the Onset of Puberty, p. 313–341. John Wiley and Sons, New York.

Rawlings, N. C., H. D. Hafs and L. V. Swanson. 1972. Testicular and blood plasma androgens in Holstein bulls from birth through puberty. J. Anim. Sci. 34:435.

Resko, J. A., H. H. Feder and R. W. Goy. 1968. Androgen concentrations in plasma and testis of developing rats. J. Endocrinol. 40:485.

Secchiari, P., F. Martorana, S. Pellegrini and M. Luisi. 1976. Variation of plasma testosterone in developing Friesian bulls. J. Anim. Sci. 42:405.

Swanson, L. V., R. P. Wetteman, N. C. Rawlings, H. D. Hafs and W. T. Magee. 1971. Pubertal relationships of some endocrine and reproductive criteria in Hereford bulls. J. Anim. Sci. 33:823.

VanDemark, N. L. 1956. Quantitative aspects of semen production in bulls. p. 80-88. Proc. III Intern. Congr. Anim. Reprod. (Cambridge).

Wolf, F. R., J. O. Almquist and E. B. Hale. 1965. Prepuberal behavior and puberal characteristics of beef bulls on high nutrient allowance. J. Anim. Sci. 24:761.